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Radiography in Palaeopathology: Where next?

Radiography in Palaeopathology

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Abstract

Radiography has frequently been used during palaeopathological research, and plays an important role in the differential diagnosis of many diseases, including Paget's disease and carcinomas. Traditionally, radiographs were taken in hospitals with clinical equipment. However industrial radiography techniques have gradually become more commonly used, as their superior image quality and improved potential for diagnoses become recognised. The introduction of radiographic scanners has facilitated the digitisation of these images for dissemination and publication. However this is not all that radiographic digitisation can offer the researcher. Digital image processing (DIP) allows the researcher to focus on an area of interest and to adjust the brightness and contrast of the captured image. This allows the investigation of areas of high radio-opacity and radio-lucency, providing detailed images of the internal structures of bone and pathological lesions undetectable by the naked eye. In addition 3D effects, edge enhancement and sharpening algorithms, available through commonly used image processing software, can be very effective in enhancing the visibility of specific features. This paper will reveal how radiographic digitisation and manipulation can enhance radiographic images of palaeopathological lesions and potentially further our understanding of the bony manifestations of disease.

Keywords: radiography, digitisation, digital image processing, palaeopathology, differential diagnosis, curation.

Radiography has frequently been used for the diagnosis and interpretation of certain pathologies, for example carcinomas, Paget's disease, fractures and ankylosing spondylitis (Ortner 2003, 503-544 and 574-577; Roberts 2000, 349; Aufderheide and Rodrígues-Martín 1998, 102-3 and 414-5). However radiography has not been used extensively across the whole range of diseases encountered in palaeopathological research, probably due to a combination of cost and access to suitable equipment, both of which can vary from region to region, the emphasis in palaeopathological research still being laid on the macroscopic analysis of skeletal remains alone (Ortner 2002, 6). In contrast, the examination of mummies and bog bodies is more successful in attracting funding and frequently employs the most up-to-date technologies such as Computed Tomography (CT) (Davis 2005, 135-49 and plates 7.1 to 7.5). Clinical radiographs, whilst useful for comparison with archaeological cases, will not present identical images. Soft tissue may mask subtle changes in the bone and in certain conditions superimpose soft tissue lesions over the image of the bone. Consequently the radiographic signature of many bone lesions remains largely unexplored in the archaeological literature. It is also apparent that only a relatively small number of radiographs are published (for example, compare the numbers of photographs and radiographs in any palaeopathological text book: Aufderheide and Rodrígues-Martín 1998; Ortner 2002; Roberts and Manchester 1995), presumably partly due to the difficulties encountered when creating publication standard radiographic images.

The aim of this paper is to show how industrial radiography, applied to the investigation of human bone can enhance our detection, understanding and diagnosis of pathological lesions and why this technique is superior to clinical radiography. The principles of radiographic imaging will be summarised and the advantages of digitising film images for curation, dissemination and image interpretation are discussed and illustrated with a number of palaeopathological case studies.

Industrial radiography is used in the non-destructive evaluation of objects as diverse as metal welds and castings, plastics, fibre reinforced composites and foodstuffs. It is also widely used in the investigation of cultural material including ceramics, paintings, textiles, and archaeological metalwork (Lang and Middleton 2005). Industrial radiography differs from clinical radiography in that it is not governed by the overriding need to protect a patient. Instead the detail of the techniques used in industrial radiography can be adapted to optimise the image quality for each of its varied applications.

Principals of radiographic imaging

X-rays, like visible light, are a form of electro-magnetic energy but they are invisible, travel in straight lines and have much greater energy and shorter wavelengths than light. Consequently, rather than just being reflected or absorbed, they are able to penetrate deeply into, or through, materials that would otherwise be considered opaque. X-rays are also termed 'ionising radiation' because they have the energy to liberate electrons from the atoms of the material through which they are passing, and it is this that can damage living tissues. As a beam of X-rays penetrates an object some of the X-rays will be absorbed or scattered. The amount of this attenuation of the beam will depend on the energy of the X-rays and the atomic number, thickness and density of the material. In a single exposure at a given X-ray beam energy, a thin sheet of lead (a dense material of high atomic number) may appear radio-opaque (white) whilst a dense bone such as a femur (a porous structure of a mixture of elements all with a considerably lower atomic number than lead) will appear more radio-lucent in comparison (shades of grey). Like light, X-rays cause chemical changes in photographic emulsions, related directly to the intensity of the X-ray flux reaching the film and thus can form the image of the object through which they have passed (Halmshaw 1986).

In conventional radiography, also called transmission radiography, the object lies between the source of X-rays and the image receptor – for instance radiographic film. A radiograph is similar to a black and white photographic negative. The emulsion will be darkest where the greatest number of X-rays has reached the film. The more radio-opaque the object, the lighter the emulsion as fewer X-rays will reach the film. It is these variations in the X-ray flux reaching the film that forms the image. This essentially produces an image in two dimensions containing information from the three dimensions of the object which can make the capture of some details and the interpretation of overlapping features in the image problematic. However radiography enables the non-destructive detection and recording of structures hidden within objects.

The ionising effect of X-rays can also be used to record the image without using film. For instance, computed radiography (CR) relies on the use of a photo-stimulatable screen, where electrons moved out of orbit by collision with the X-rays are trapped in a higher orbit, until they are freed by scanning the screen with a laser light. As the electrons fall back to a lower orbit they release energy in the form of light which is detected electronically and converted into a digital X-ray image.

Electrically-powered X-ray units do not produce X-rays of a single energy, but produce a spectrum of energies. For instance a 30 kV exposure is one in which the highest energies of the spectrum do not exceed 30 kV. The lowest energy X-rays, often termed ‘soft’ or Grenz rays, have a long wavelength and low powers of penetration. Higher energy X-rays, termed ‘hard’ X-rays, have shorter wavelengths and greater penetrating power.

Industrial versus clinical radiography

With fast films, florescent screens and heavy filtration of the X-ray beam, clinical radiography is designed to minimise the exposure duration and overall X-ray dose to the patient, and to eliminate the lower energy X-rays (below c. 40 kV) which are the most damaging to living tissue. However, this is achieved at the expense of image resolution and contrast.

Industrial radiography is not hampered by the same restrictions. Traditionally the radiography of palaeopathological lesions has been undertaken with clinical equipment but increasingly industrial radiography techniques have become recognised as providing improved potential for diagnoses because of their superior image quality. Beam geometry, energy, and filtration; exposure duration; X-ray dose and film selection in industrial radiography are all focused on producing high definition images. Compared with clinical X-ray images, high quality industrial images will have a much higher resolution, a greater dynamic range and show greater contrast between features of similar radio-opacity. CR produces images with a greater dynamic range than any film, although currently even the highest quality CR screens produce lower resolution images than industrial films such as Agfa D4. However when radiographing archaeological bone in a clinical setting, the use of CR can be preferable over film as it has a greater dynamic range than general medical film and therefore produces higher contrast images.

X-rays can be scattered by interaction with all the materials through which they pass and this scatter causes fogging of the film, which makes the edges of features appear blurred. Very low energy X-rays that cannot penetrate the bone do not contribute to the formation of the image but can form a significant component of the scattered radiation, increasing the fogging. Improvement in the sharpness of image detail can be obtained through careful filtration using thin metal sheet or foil to remove these very low energy x-rays from the spectrum. The improvement in image quality produced by appropriate filtration is illustrated in Figure 1. This shows a first metatarsal with a lytic lesion at the distal metaphysis, which is characteristic of gout. Further lytic lesions were present on the fourth and fifth metatarsals of this individual, from St Mark's Station, Lincoln (medieval Carmelite Friary; Isaac and Roberts 1997). Both radiographs were taken at 60 kV: the right image was taken using a plastic cassette whilst that on the left was taken using an aluminium cassette. The right image has more contrast, but some areas of bone are overexposed and therefore are not recorded on the radiograph (e.g. the medal side of the distal end). In the left image the aluminium cassette has acted as a filter and the detail is clearly sharper. Because the aluminium lid of the cassette is between the object and the film this has not only filtered the primary beam but also removed low-energy scatter generated within the object itself. The filtered image is also slightly lower in contrast but this has improved the rendition of detail as, whilst the detail in the thicker areas of bone is still visible, the thinner areas are not so overexposed.

A step wedge or other agreed standard should be included in all radiographic images to act as an image quality indicator (IQI). This is especially important if bone densities are being investigated. Variations in processing protocols, the condition and temperature of the processing chemicals and the use of different X-ray units can produce variations in the contrast of the images produced, even if the same film and exposure parameters have been used.

O'Connor and O'Connor (2005) discuss the radiography of pathology in bird bones, however many of the observations that they make relating to equipment choice, film selection and radiographic technique are equally valid for the radiography of human remains.

Sharing and publishing images – some solutions

As radiographs became more routine in osteological research, their dissemination has become a priority. Viewing and handling of film radiographs inevitably leads to the degradation of the radiograph. Prolonged exposure to light causes photodegradation of the image and the delicate emulsion is also prone to physical damage, for example scratching the surface and sticky fingerprints, every time the film is slid out of its protective envelope and put on a light box. The reproduction of X-ray images by photographic techniques or by digitising them with a light box and flat bed scanner often produces disappointing results. The introduction of industrial radiographic scanners is revolutionising our ability to capture information in all the tones of the X-ray image in a digital form (jpg, tiff, etc.). Once digitised, the original X-ray image can be archived in suitable controlled storage conditions to ensure its long-term survival. The digital copies can be stored electronically and used for teaching, discussion with colleagues, printed to film or paper, or reduced in resolution (as appropriate) for inclusion on web sites, publication, posters and museum displays. Through digitisation, endless numbers of identical copies may be produced and can be distributed among members of a research team, for example osteologist, archaeologist and contractor and viewed countless times without degradation of the image quality or loss of information.

Figure 2 is of the fractured lower legs of a Roman skeleton from Baldock, Hertfordshire (Roberts 1984). The old radiograph, on the left, has deteriorated over time, probably due to poor chemical processing in combination with extended exposure to light whilst in use as teaching material. The level of contrast, in particular, is much reduced. Digitisation of the radiographic film has preserved the image for our archives, and has allowed it to be investigated using digital image manipulation (right), greatly improving the sharpness and contrast. The arrow in this image pointing towards a cloaca was an annotation made on the film in pen for teaching purposes. Digitisation has removed the need to annotate films directly as the arrow and any additional notes would be made to a digital copy.

Digital Image Processing (DIP)

It is possible to digitise an X-ray film by photographing it on a light box using a digital camera or by scanning it using a conventional flat bed scanner converted to digitise transparent media. However, the dynamic range of X-ray images is very much wider than, for instance, a photographic negative and it is unlikely that either of these approaches will capture detail equally well from all the densities (from black through to white) which have been recorded on the film (O'Connor and Maher 2001). An industrial X-ray film scanner is now used routinely at the University of Bradford.[1] It is designed specifically to be used to capture the detail in all the optical densities of the film, including variations not distinguishable by the naked eye. Digital image processing (DIP) using commonly available image processing software (such as Adobe Photoshop and Paint Shop Pro) of the captured data allows us to improve the visibility of these features to an extent that was not previously achievable.

[1] Agfa FS50B industrial X-ray film scanner with Radview capture software.

DIP is often regarded as a means of falsifying information. This is possible in unscrupulous hands, just as convincing photomontages could always be created by talented photographers. Used responsibly, DIP is a means of improving the visibility of captured information. DIP can be used to rescue information from technically poor X-ray images or those that have degraded over time (Figure 2), however it cannot be used to create information that was not captured in the first place, and should not be seen as a substitute for good radiographic practice. There is no problem in using digitally manipulated images for comparative purposes where, for instance, only the brightness or contrast has been adjusted to improve feature visibility when there is a suitable IQI in the image. However, if techniques such as sharpening, edge enhancement or texturing have been applied it would be essential that the original image be published alongside the enhanced version.

Magnification of detail or converting the image from positive to negative form are achievable at the click of a button and can reveal details which might otherwise have been overlooked. Figure 3 is a radiograph of a possible case of osteomalacia from the medieval Blackfriars cemetery in Gloucester (Wiggins et al. 1993). Macroscopically the ossa coxae are paper-thin and very dysplastic, with thumb sized depressions in the centre of the ilia. The rest of the skeleton is notably very light, with very thin bone cortex, and a ‘pinched’ appearance to many muscle attachment sites, however no micro-fractures have been observed. Digitisation of the radiograph has allowed the researcher to enlarge an area of interest, in this case where the ilium becomes paper-thin. This area displays a total loss of trabecular bone, a sclerotic margin and some ovoid areas of radio-lucency. Could these areas be typical of osteomalacia?

The investigation of very dark or light areas of an image and also the discernment of detail within features which, to the naked eye, may seem to be just an undifferentiated grey can be achieved through reassigning the greyscale values of the pixels which make up the image. This can be done through adjusting the picture’s contrast or brightness, or through more complex histogram adjustments. These adjustments are particularly useful in revealing the details of the internal structures of bone and pathological lesions. 3D effects, edge enhancement, sharpening algorithms and pseudo-colour imaging of specific grey levels can also prove effective in highlighting specific features (O’Connor et al. 2002).

Figures 4 and 5 are radiographs of the cranium, vertebra and ribs of a 19th-century individual from St Peter’s Wolverhampton (Arabaolaza et al. 2005; Adams J and Colls K in prep). Macroscopic analysis of the skeleton revealed the sunburst lesions on the vertebra and ribs (Fig. 4), and multiple small lytic lesions with periosteal new bone formation characteristic of metastases on many bones throughout the postcranial skeleton. A small area of porosity visible on the cranium led to the second radiograph (Fig. 5), which reveals multiple lytic lesions across the vault, many of which are contained within the diplöic space. This is a case of metastatic neoplasm, probably osteosarcoma.

Conclusion

Radiography can reveal pathological lesions even when there is little or no external macroscopic manifestation and provides us with more information about the internal architecture and spread of specific conditions than visual inspection allows. Whilst the radiographic signature of particular diseases like Paget’s disease are well understood; others, such as dental granulomas and cysts, are yet to be fully characterised in palaeopathology. Digitising film radiographs using a dedicated X-ray scanner improves their diagnostic potential through the application of digital image processing to enhance the visibility of features of interest. It also facilitates the archiving and dissemination of radiographs and aids the preparation of quality images for publication. Radiography should be used and published more routinely in palaeopathological research.

The palaeopathological community should concentrate less exclusively on external appearances and give much more attention to the internal structures revealed by radiographic images. We should embrace and develop the use of industrial and digital radiographic techniques, free from the anxiety about tissue damage that has bedevilled clinical radiography. By this means a new standard of radiographical excellence may be achieved.

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Literature cited

Adams J and Colls K (eds.) (in prep) ‘Out of darkness, cometh light’ Excavations in the overflow burial ground of St. Peter's Church.

Arabaolaza I, Ponce P and Boylston A (2005) St Peter’s Collegiate Church, Wolverhampton. Report on the human skeletal remains. Bradford: Biological Anthropology Research Centre, University of Bradford; Unpublished.

Aufderheide AC and Rodrígues-Martín C (1998) The Cambridge encyclopedia of human paleopathology. Cambridge: Cambridge University Press.

Davis R (2005) Radiography: archaeo-human and animal remains. Part I: Clinical radiography and archaeo-human remains. In J Lang and A Middleton (eds.): Radiography of cultural material. Oxford: Butterworth Heinemann. (2nd edn).; 130-149.

Halmshaw R (1986) Industrial Radiography. Mortsel: Agfa-Gevaert.

Isaac L and Roberts C (1997) Cemetery at former St Mark’s railway station, Lincoln. Bradford: Calvin Wells Laboratory, University of Bradford; Unpublished.

Lang J and Middleton A (eds.) (2005): Radiography of cultural material. Oxford: Butterworth Heinemann. (2nd edn).

O'Connor S, and Maher J (2001) The digitisation of X-radiographs for dissemination, archiving and improved image interpretation. The Conservator 25, 3-15.

O'Connor S, Maher J, and Janaway R (2002) Towards a replacement for xeroradiography. The Conservator 26, 100-113.

O'Connor T and O'Connor S (2005) Digitising and Image-Processing Radiographs to Enhance Interpretation in Avian Palaeopathology. In G Grupe and J Peters (eds.): Documenta Archaeobiologiae 3: Feathers, Grit and Symbolism. Birds and Humans in the Ancient Old and New Worlds. Rahden: Verlag Marie Leidorf GmbH; 69-82.

Ortner D (2002) Palaeopathology in the twenty-first century. In K Dobney and T O'Connor (eds.): Bones and the man. Studies in honour of Don Brothwell. Oxford: Oxbow; 5-13.

Ortner D (2003) Identification of pathological conditions in human skeletal remains. London: Academic Press (2nd edn).

Roberts C (1984) The human skeletal report from Roman Baldock, Hertfordshire. Bradford: Calvin Wells Laboratory, University of Bradford; Unpublished.

Roberts C (2000) Trauma in biocultural perspective: past, present and future work in Britain. In M Cox and S Mays (eds.): Human osteology in archaeology and forensic science. London: Greenwich Medical; 337-356.

Roberts C and Manchester K (1995) The archaeology of disease. Stroud: Sutton (2nd edn).

Wiggins R, Boylston A and Roberts C (1993) Report on the human skeletal remains from Blackfriars, Gloucester (19/91). Bradford: Calvin Wells Laboratory, University of Bradford; Unpublished.

Figure captions:

Figure 1: First metatarsal with lytic lesion characteristic of gout (St Mark's Station, Lincoln). The image on the left was taken using an aluminium filter, whereas the image on the right was not filtered.

Figure 2: Fractured tibiae and fibulae with osteomyelitis (Baldock, Roman). The old radiograph (left) appears to be deteriorating. Digitisation has preserved the image for our archives, and allows it to be investigated using digital image manipulation (right).

Figure 3: Possible case of osteomalacia from Blackfriars, Gloucester. Digitisation allows the researcher to magnify an area of interest, revealing a total loss of trabecular bone, a sclerotic margin and some ovoid areas of radio-lucency.

Figure 4: Sunburst lesions on vertebra and rib from St Peter's Wolverhampton.

Figure 5: Cranium of individuals from St Peter's Wolverhampton revealing multiple lytic foci.